LBNF Spectrometer: Architecture & DutyFactor

Paul Lebrun
(for the LBNF Spectrometer group.)

ND/Fermilab

Outline

- My list of task, very broad overview
-
- Architecture & DAQ rate, counting strategy: relations, trade-of, etc
-
- Progress on Duty Factor estimate, status of T1315. Status, start of discussion on what's next.

Task list, one perspective.

- LBNF Spectrometer primary Beam line.
  - We don't have one. This is a problem.
- Silver lining: we have a chance of building the way we want: Optics, beam spot size range, intensity range, instrumentation.. What are the specs?
-
- Architecture & DAQ rate, counting strategy: relations, trade-of, etc
-
- The spectrometer itself : aperture, components, technology
-
- Progress on Duty Factor estimate, status of T1315. Status, start of discussion on what's next.

Introduction: Motivation

A direct measurement of the neutrino's progenitors, with the entire target and focusing system turned “on” implies a stringent limit of the maximum duty factor one can expect, $6\text{x}5e^{-5}/60 \sim 5e^{-6}$. The first terms is the number of pulses per seconds the LBNF horn power supply can deliver during the M.I 4 seconds long spill, the 2nd term is the pulse duration where we have a useful focusing field, the last term is the M.I. fixed target repetition rate.

If a statistical precision of ~ 1% for a cell which is 1% of the entire 5D phase space, we need $1e^{6}$ pions. Running at 20 MHz, it will take less than a day to the take the data, assuming that (I) we take one proton per 50 ns long “time bin” (ii) assume a factor of ~1/3 inefficiency due to empty time bins or more than one proton per time bin.

Not bad, but..

Introduction: Are we there yet?

We need to repeat these measurements many time, to study the effect of horn & target misalignment, different targets, cooling water flow rate in the horn, proton beam parameters, etc, etc…

There will be pressure to do these measurements quickly: we will be using spare equipment!.

20 MHz is achievable for the tracking system. (But costly, if large aperture). Is it for the RICH, muon/pion calorimeter?

Is the Poisson counting efficiency fair? (T1315 studies)

We could accumulate data over all the 100 cells of phase space at once, large aperture spectrometer

We could relax the requirement of one proton per DAQ “time bin”, and accept overlapping events in the spectrometer.

Why one proton at a time?

Because it simplifies the analysis, and thereby improves the estimate of our systematic uncertainty. However, it is a costly option: we could be off by one order of magnitude in the duty factor, as the current analysis of the data from T1315 suggests.(see later)

This was justified because the proton spot size on target, real vs replica of the chase, was assumed to be very different. However, at M-T6-1 test area, for ~ 2.5 to 5 mm beam sigma, only a factor 2 to 3 bigger than what we plan for the NuMI target, 1.6 mm, ..(and slightly bigger if we use the RAL target.)

But there is also a poorly explored (so far) motivation: Pattern recognition capabilities in the track & PID system, in presence of copious EM backgrounds. We simply can not bluntly reject the events that are too messy, as there are hidden correlations between π^0 and charged π production.. While we expect only 0.1 π per proton in a 15” squared area, we do have on occasion many e^+e^- pairs into the tracking system.

May be a few protons at a time?

So, if the pattern recognition capabilities of the LBNF spectrometer is such that we can tolerate EM background, and if the emittance/spot size on target can be controlled to good (TBD!), then I have no objections to running at multiple protons on target.

We should design the beam line allowing this option.

Note: the emittance of the M.I. could be made lower for the LBNF Spectrometer M.I. cycle, given our intensity requirement (no slip stacking, lowest booster intensity possible, assuming Sea-Quest does not request beam for the same spills…)

Motivation for getting this flexibility: our duty factor could a factor 3 to 10 lower than estimated based on a "perfectly smooth spill"

Status of T1315

Studies of the M.I. slow extraction process: Quantitatively, how smooth is the beam intensity during the 4.1 second spill? While the M-Test beam line is not the LBNF primary proton line, we could and should learn how to make such measurements..

Did this with borrowed equipment (PREP (SCD), SiDet (PPD), Neutrino Division (Rick Tesarek's counter), PPD Detector Electronics,.. got accurate profiles of the arrival time of 120 GeV at M-Test.

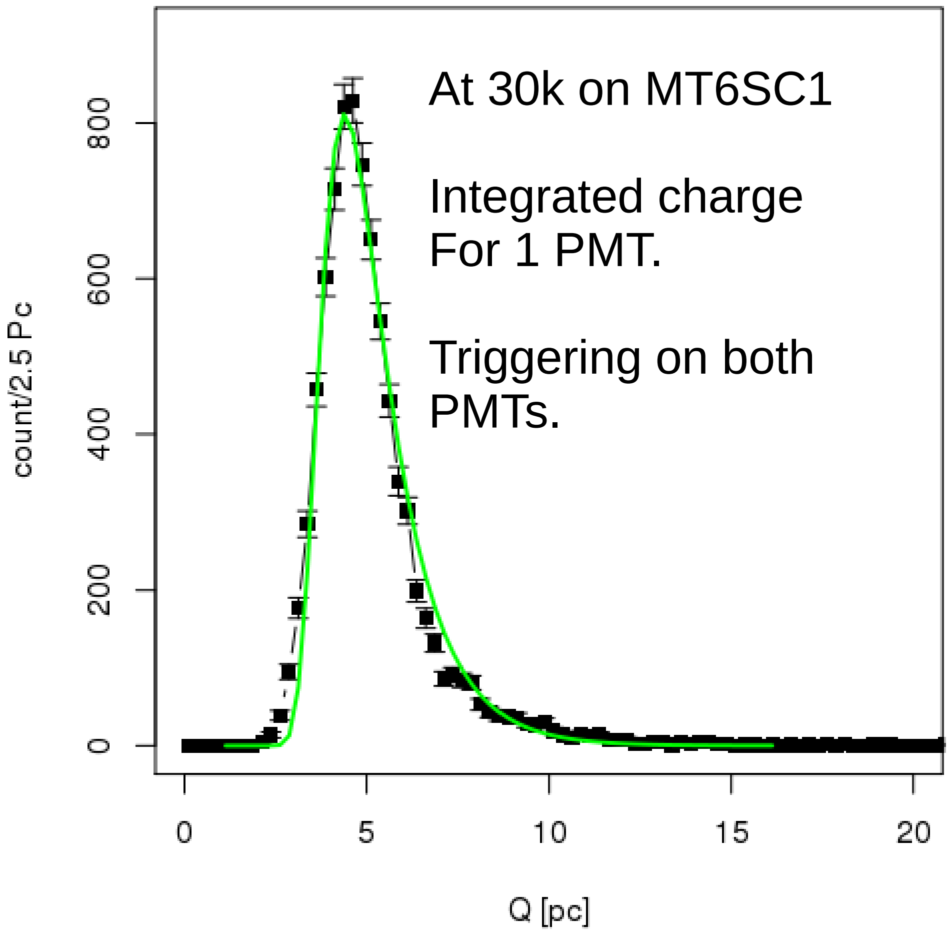
First some slides presented at the Test Beam meeting.., 2nd, summary of recent results, 3rd, preliminary conclusion.

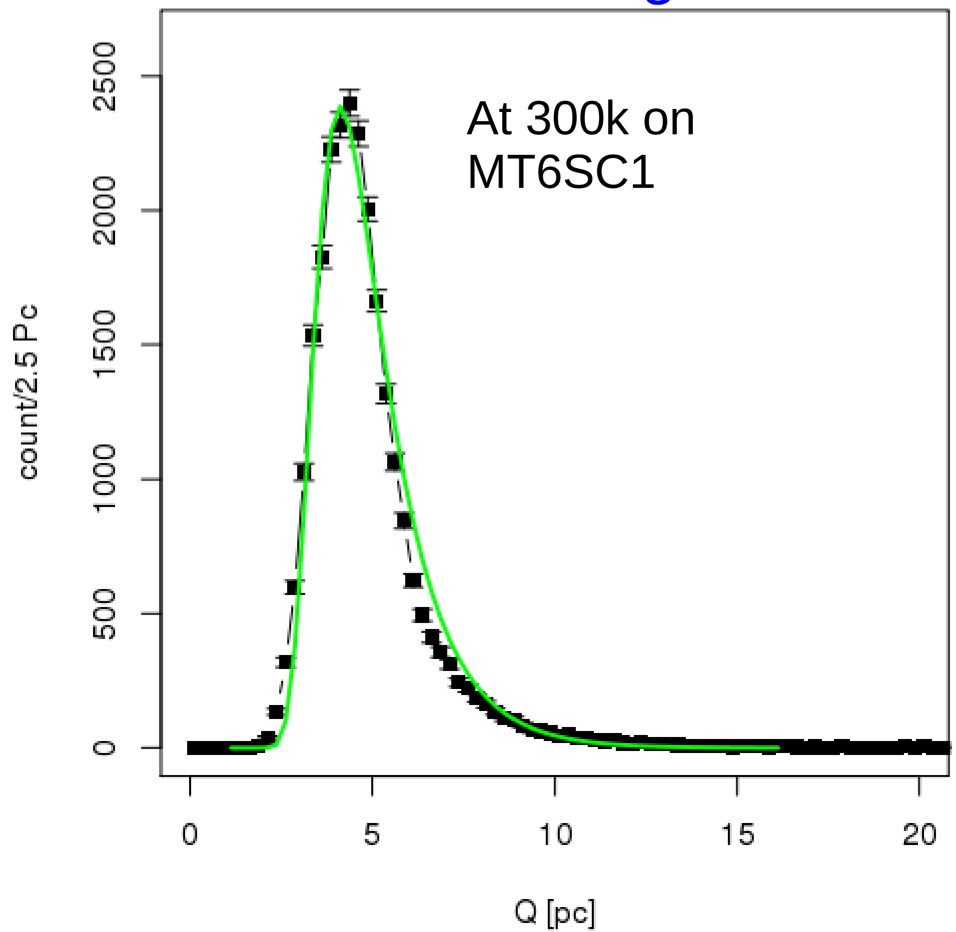
Status: data taking done, Analysis in progress

T1315 Next: Tracking & Beam timing structure measurements, with CMS Pixels or Silicon tracker prototypes.

Preliminary results...DRS4 spectrum

Shown on June 12, Test-Beam meeting

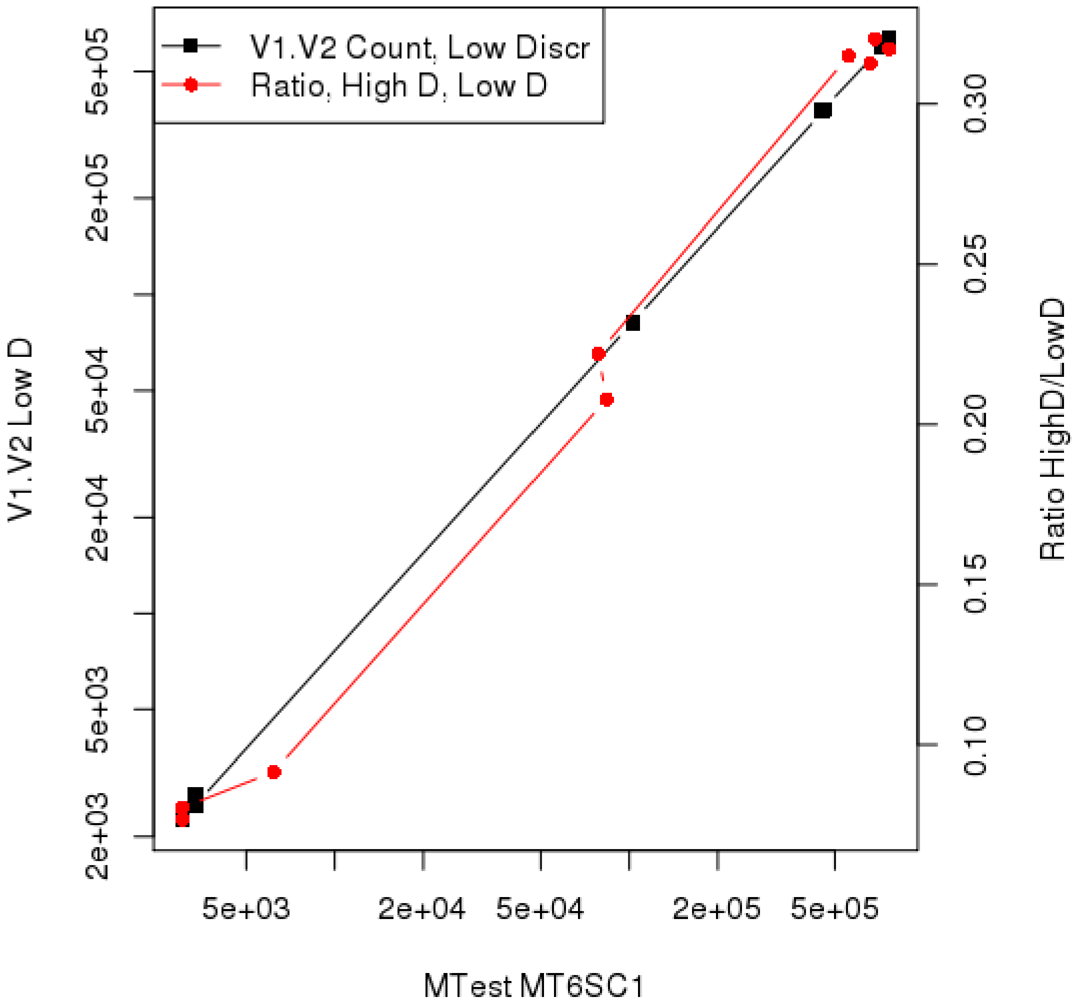




No evidence for doubly occupied r.f. bucket !

Why?

Preliminary results..."Simple scalers" Low vs High discriminator thresholds.



Data taken during Memorial day week-end

The probability to observe a "high" right-side PMT signal (in coincidence with left-side PMT) is proportional to the beam intensity, as determined by FTBF counter MT6SC1.

The ratio of "high/low signals" does not seem to constant..

=> high signal is not always due to interacting protons in the scintillator, or upstream (Cerenkov windows, MT6-1a equipment, etc..) Indirect evidence for "more then on proton per r.f. bucket"

=> If so.. gives – indirectly – an upper limit on the effective Duty factor.

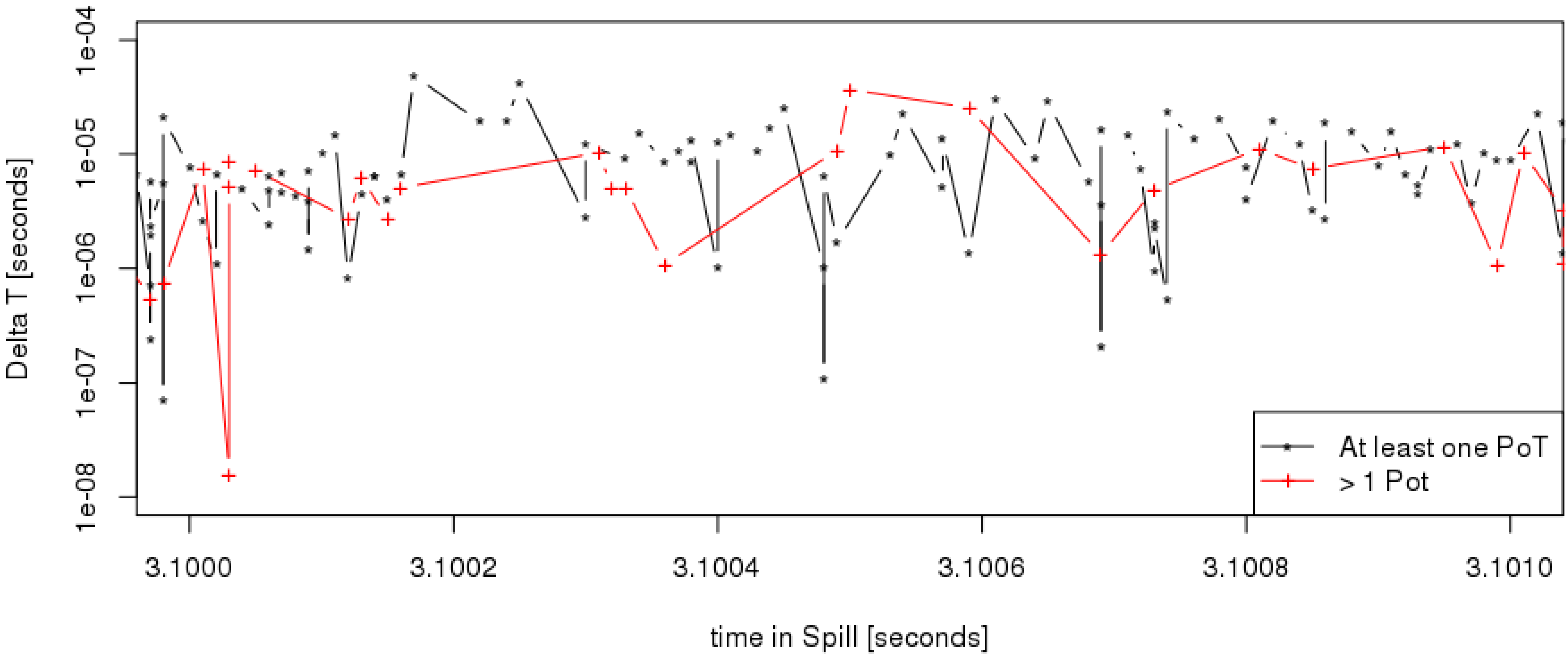
Again, where is the evidence for double integrated charge on the DSR4 spectra?

Does the simple dual PMT counter (with “vintage” PMT/Base and Lecroy fan in/out) has the required rate capability?

Two recent additions to our setup: (I) The NimPlus/Captan DAQ board, which register every few ns long pulse during the spill (ii) “good” borrowed counters to look for doubly occupied r.f. buckets.

Preliminary results... NIMPlus traces.

Shown on June 12, FTBF meeting



(Data taken yesterday...)
This is based on a small portion of a NimPLus trace, for one spill, showing the delta T between two consecutive signals from our counter, vs time into the spill. (on ly 10 mSec, for sake of brevity). Again, we have the entire spill.

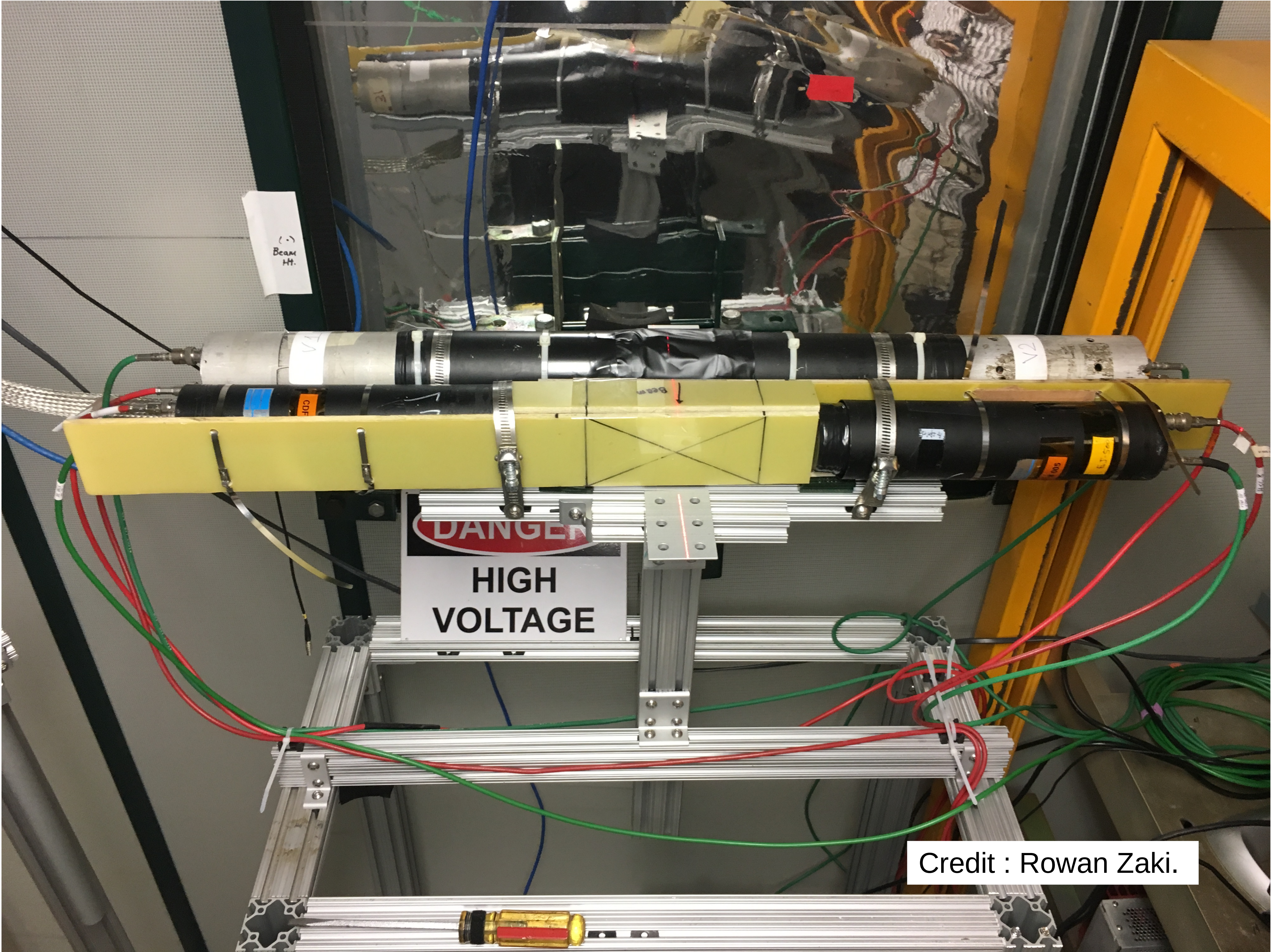
Not Poisson distributed... quite complex.

Since then, many more similar spectra.

Also added the M.I. turn marker, ("$AA"), to correlated Booster Batches to the delivered beam.

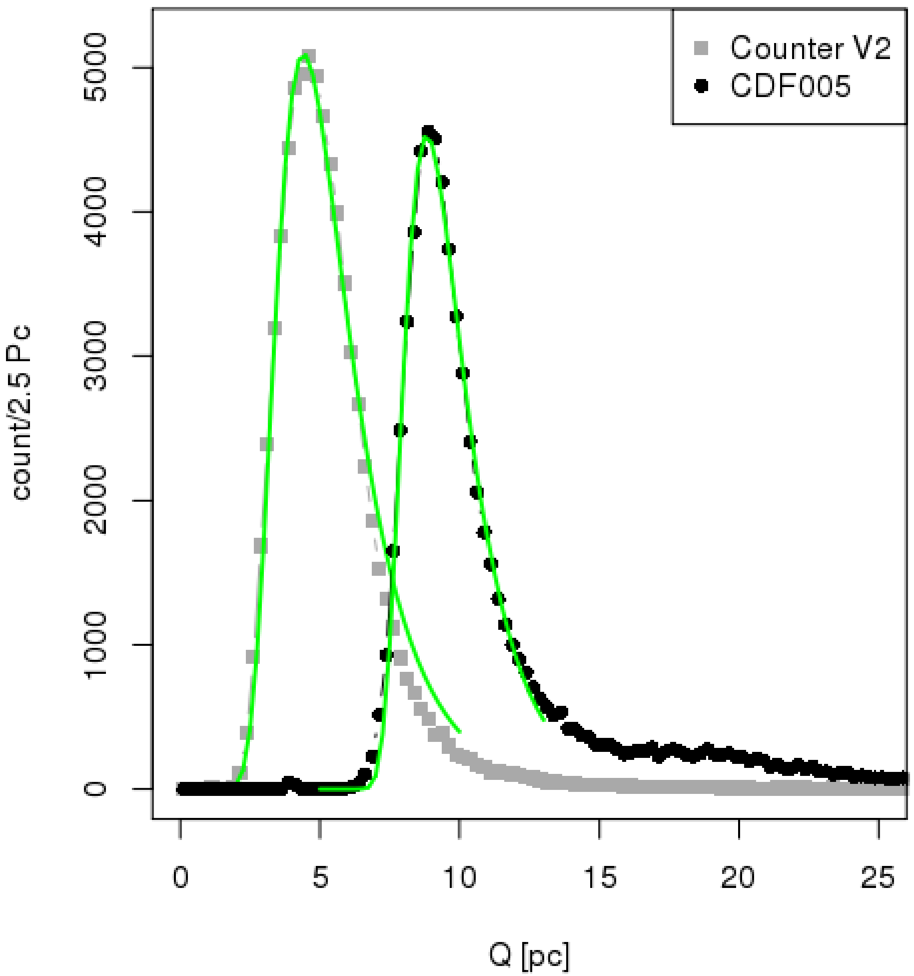
Last Friday, received from Rick Tesarek a thicker counter, better PMT/base. (Thanks Rick).

Installed it, took data at 5,000 cnts/spill on MT6SC1, 30k, 300k.



Credit : Rowan Zaki.

Comparison of the time integrated charge distribution



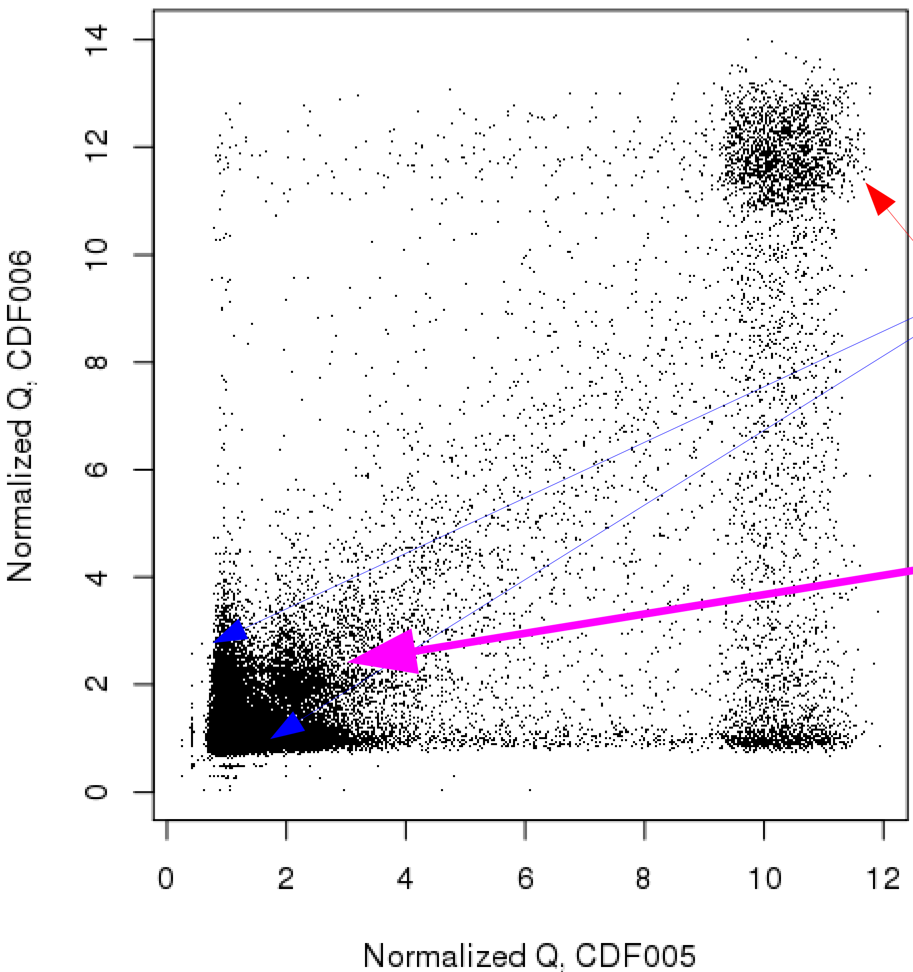
DSR4 data. Based on ~74,811 triggers.

Much better (x2, at least) de/dx resolution.

This was taken on July 1 & July 2 , at 30,000 proton per spill on MT6SC1. About 25,000 V1.V2 coincidence. We triggered on V1.V2.CDF005. (triggering on V1.V2.CDF006 makes little difference.)

Allows to see a hint for “double occupancy” At Q ~ 2*9 pc = 18 pc. But we can do better.. Using CDF005 and CDF006

Detection of two (or more) particles per r.f. bucket.



DSR4 data, CDF005 vs CDF06 integrated charge.

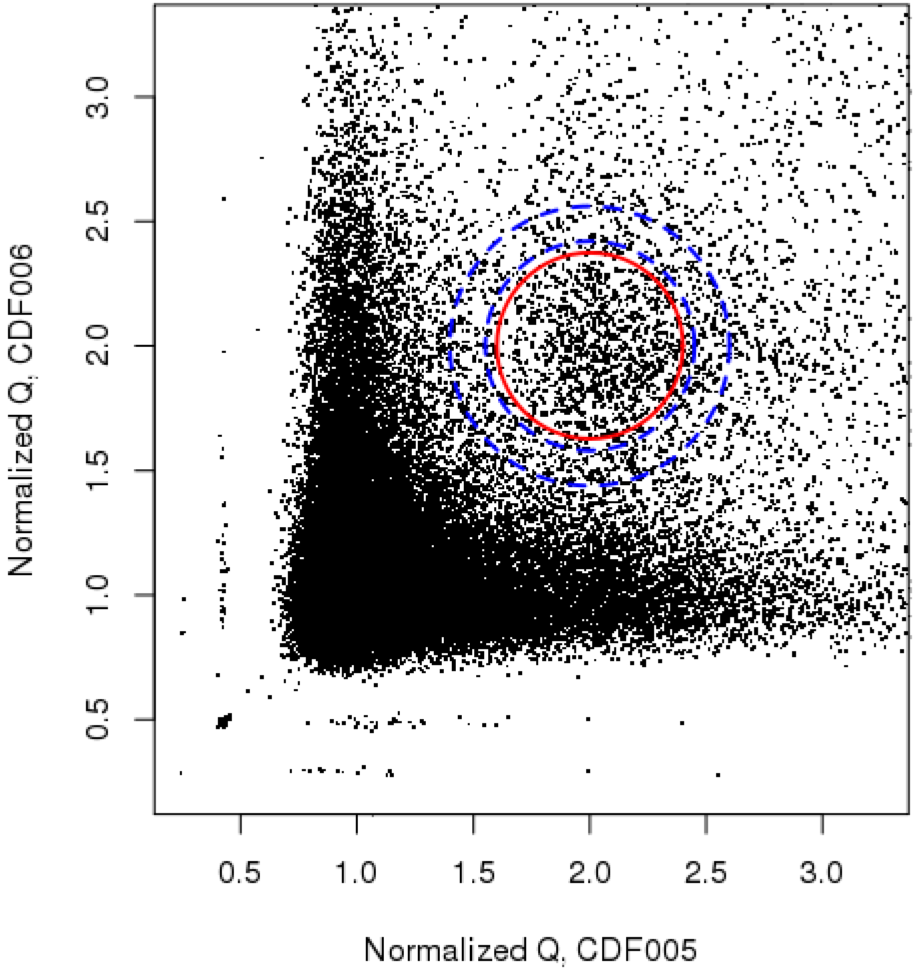
Dedx (Laundau) + resolution, independent amplitude (distinct scintillators)

Signal saturation, many particles of hadronic shower.

Two particles, in both counters.

Note: CFD005 located downstream of CDF006.

Same DSR4 data, closer look.



The relative calibration is determined by Landau fit of the data.

The relative width of the resolution curve on the previous plot is about 10% to 15%. Draw a circle at Q(2.,2.), R = 0.4 . Draw two other concentric circle, to determine a background region.

Assume this “background” is flat. Statistical significance of this 2D bump ~ 8.7

Get (0.5 +- 0.05 %) probability for a “double occupancy signal”.

Double saturation probability: 2.7%.

“Multiple particles”/r.f. bucket versus beam intensity.

Beam Intensity (MT6SC1 cnts/spill)	Double Occupancy (%)	>~ 4 (Saturation) (%)
5k	0.58 +- 0.07	2.4 +- 0.1
30k	0.51 +- 0.05	2.7 +- 0.1
300 k	0.56 +- 0.1	3.15 +- 0.1

Uncertainties are statistical only, with a rather crude model for the double occupancy.

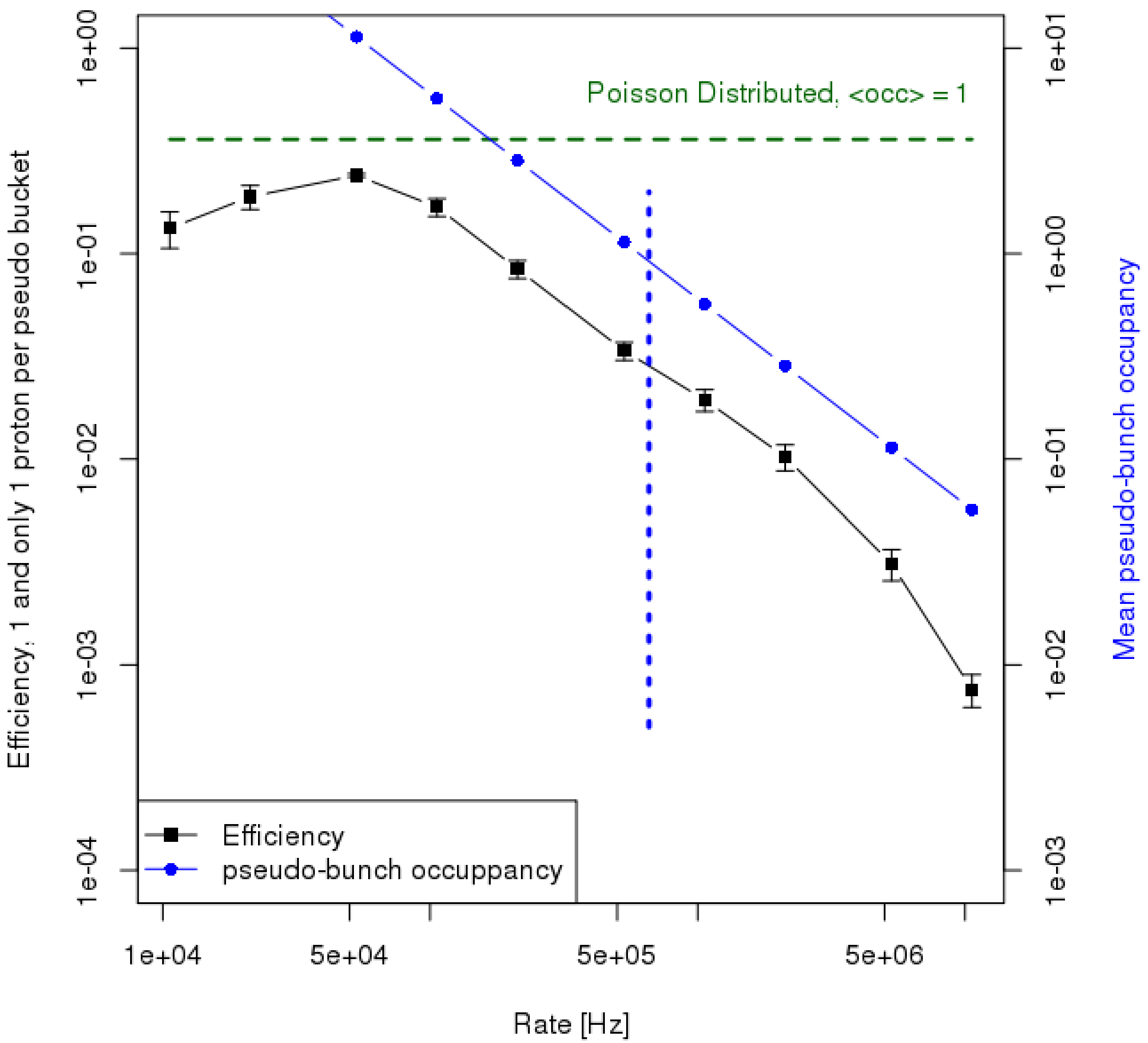
Yet, it is obvious that the neither the double occupancy nor the saturation rate probabilities scale wit the beam intensity. Note: at the higher intensity for this study, ~ 250000 counts on V1.V2, the single occupancy rate is ~< 0.1%.. So, not too surprising, perhaps, that the double occupancy is lower than ~ 0.5%.

We are seeing hadronic interactions upstream of V1.V2, and in CDF005, in the V1, V2, CDF006 and the 5mm thick J10 plates acting as support struct. and δ-ray absorbers.

Back to the arrival time of the V.V2 triggers, using the NimPlus/CAPTAN boards. (Thanks to PPD/SCD)

More analysis coming, related to the arrival time with respect to the turn marker, meanwhile I have the preliminary version of the summary plot, showing the “effective duty factor”, i.e., the effective DAQ rate vs “time bin” duration.

Summary plot, due to few MHz – kHz fluctuations in the beam intensity.



Based on NimPLUs profile

The “Rate” is the inverse of the (arbitrarily) chosen “time unit” or “pseudo bunch” duration.

Since the FTBF is limited to ~ 1 10^6 particle per spill, our relevant range of rate is ~20 time lower than what could be done for LBNF Spectrometer.

Yet, the optimum efficiency for “one and only one proton per pseudo bunch” is at lower rate, by a factor 10, or, conversely, at the rate at which the mean occupancy is one, our effective eficiency is 10 lower then the one dictate by Poisson law.

More information can be obtained from the existing data set, as we can correlate the probability of get a proton in a given r.f. bucket, with the M.I. turn marker, and/or the abort gap.

To discussed next time...

Conclusions (for today..)

Should we required one and only one proton per “time unit”, our duty factor could be rather low, (10x), compared to a naive estimate based on a perfectly smooth spill.

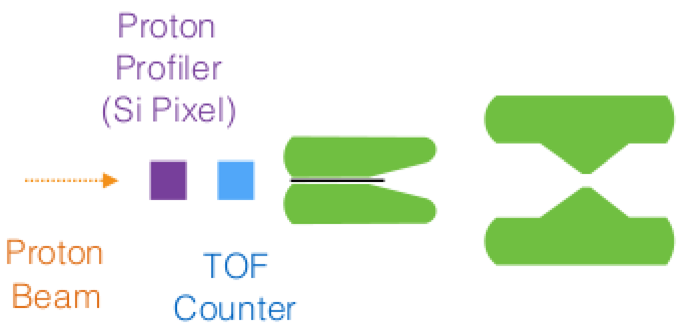
We should consider relaxing this requirement, however, in turn, this place further demand on the design of pattern recognition capabilities of the tracking/PID systems of the LBNF spectrometer.

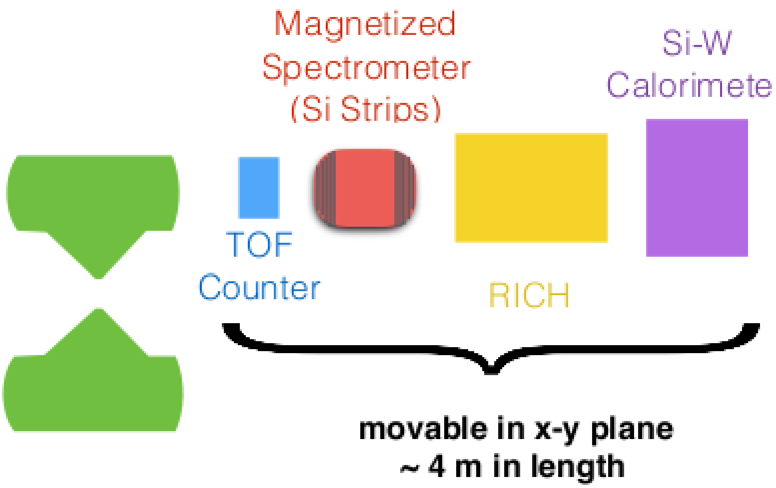
Our next step is to work on the LBNF simulation effort, the design of the LBNF slow spill primary proton beam line, including siting, and the testing o the some of LBNF Spectrometer components, the 1rst one being the tracking system, probably based on LHC strip/pixels readout.

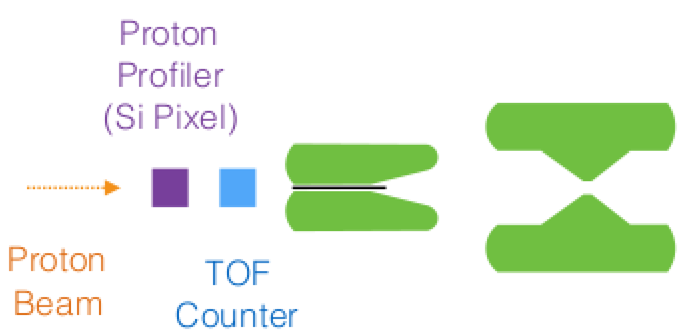
Backup: Some slides slides shown at the collaboration meeting.

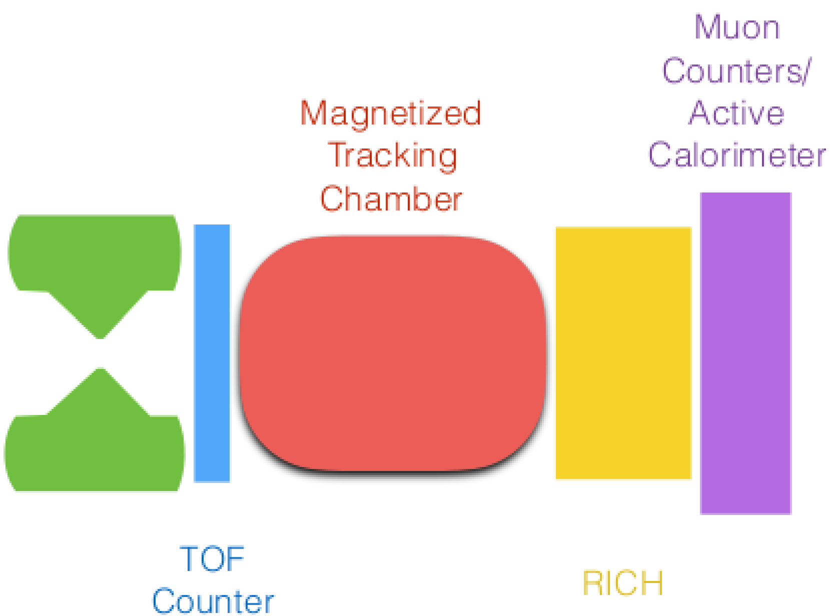
Introduction: The Spectrometer Concept, “Ex-situ”

Different architectures possible...









Credits: Laura Fields

Studied in more detail:

A large aperture dipole magnet (sq m.), small tracking system.

Avoid secondary interaction in the yoke/pole tips of the magnet. Once one gets into the details, one quickly realize..

If a ~1% relative precision on the flux (on axis) is our goal, this will not be an easy project...

A focused effort will be required.

Previous effort: learned lessons..

Lessons from MIP (Jonathan Paley) : A candide, honest on what has been done..

- The good (precision tracking, training ground for young physicists)
- The bad: unexpectedly large systematic effects in final result (hadron modeling,...)
- The “beauty-impaired” : technical difficulties, not enough well focused man-power.

Long time to publication, such analysis are man-power limited and tricky. (also true for NA61).

The LBNF Spectrometer effort is substantial, we should not underestimate it (~ 100 physicists)

Other ongoing efforts:

- NA61 (Alysia Marino)
  - New data has been taken recently, more to come. Analysis in progress..
  - If relying on cross-sections, then, must take data in a broad momentum range, P >~ 30 GeV in North Area at CERN.
  - Good discussion on “thin” vs “replica” targets: both have data sets are needed.. If long target, and Z-vertex info, difficult to analyze.
  - NA61 has currently no plan to operate beyond 2025, so DUNE will need a place to study hadroproduction and the flux from 2.4 MW targets & horns.

- US-Japan Collaboration for T2K (Jonathan Paley).
  - Thin target, exquisite precision tracking: emulsion + silicon strips.
  - In progress, DOE has allocated some $$.
  - Area of common interest: PID, silicon tracking => path for collaboration.

A staged & iterative approach:

- Need to understand the detector technology, and train the next generation of HEP physicists

- Model, measure, correct model and measure again.. (Bob Zwaska)
  - The LBNF target (and horns) is likely to change (the strip lines pads on the NuMI horn have changed.. twice)..
  - New data on hadro-production will be available (NA 61, other effort(?)

- Could, conceivably, have impact on current round of neutrino experiments at Fermilab, if the NuMI horns are placed in front of an early version of the Spectrometer
  - But it is difficult to get to a timely scenario..

The work has already started...

- ND, AD, CD, PPD are involved.

- Preliminary siting studies (Jonathan Lewis, Dave C.), Fermilab Fixed Target area.
  - SeaQuest hall, M-Center, NWA, M-East

- At FTBF, T1315: Study of the M.I + S.Y. slow spill extraction "smoothness": we need to understand better the duty factor of the LBNF spectrometer DAQ.

- Detector technology discussions.

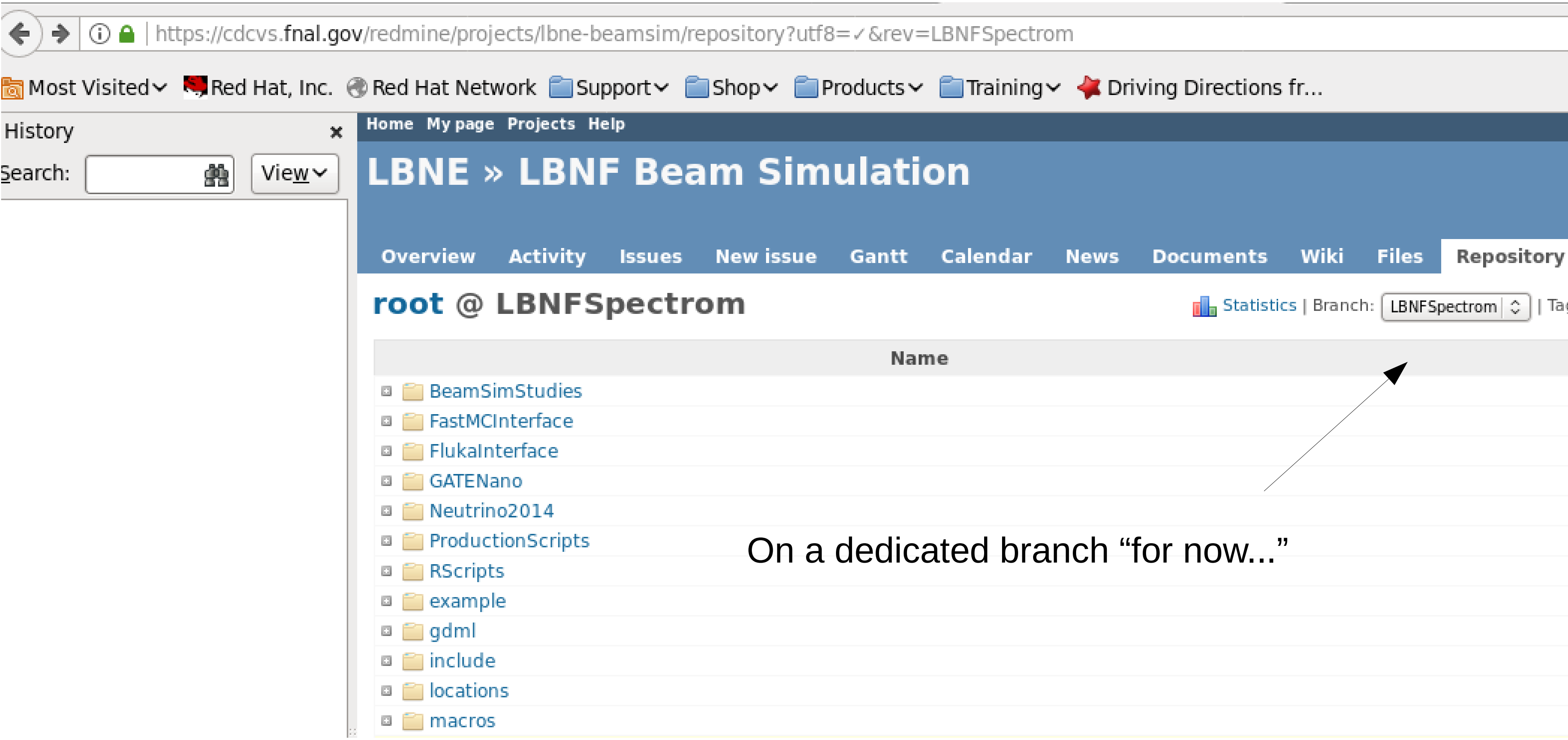
- Simulation effort.

- Thoughts on target/horn alignment (and keep this alignment!) In close collaboration with LBNF Beam group..

DAQ rate, Duty factor.., T1315.

- If DAQ small aperture, and if we can run at ~ 53 Mhz, if spill intensity perfectly smooth, we could conceivably take enough data for one flux measurement in a few days running time. (With one PoT, at most, per r.f. bucket., 50 μsec horn flat top
- But we need to study mis alignments, study the performance of the spectrometer.

- The intensity during the spill will fluctuate (B. Zwaska talk), an intrinsic feature of the beam in M.I. And it will depend on the beam line.
- We need to educate our self how to quantify the expected duty factor.
- This can be done with existing (almost) hardware, at FTBF.
  - Counter are installed, prelim. DAQ.
  - DAQ modules, MIN+, and CAPTAN boards assembled and firmware mods being discussed..



On a dedicated branch “for now...”

Detector Technologies for the LBNF Spectrometer (Dave Christian)

Review of Silicon Strip detector availability

Silicon strip wafer do exists..

No readout chip for 53 MHz operation.. but ~ 14 MHz possible. Need to purchase chips, though.

Easy to integrated if small aperture tracker.

Conventional PWC also (briefly) discussed.. Also, micromegas mentioned

Other, such as pixel detector suggested.. Need more work to show that they are really needed.

TOF & PID : the most advanced part of the problem. If 25 ps resolution possible, then, only one RICH counter is needed, which greatly simplifies the spectrometer.

In addition: The “Silicon screen”

A device that measure the position of the charge particle flux, integrated over all momenta and direction, at the entrance of the spectrometer.

Removable. “Advanced beam loss monitor”. Simplified version exists in NuMI.

Same device installed both in the real chase and in the ex-situ replica of the chase.

We would run the real neutrino beam line at low intensity (~1/10 of nominal), measure the charged particle flux of axis, subtract the residual radiological background, and compare to the flux in the chase replica

==> Cross-check of an overall normalization factor..

Feasible with LHC-era Silicon Pixel technology (55x55 microns pitch).

LBNF Spectrometer & LBNF project.

In addition to the “Silicon Screen” in the real chase, we also discussed possible scenarios for horn + strip line testing.

Impact the layout of the horn testing area, and the horn power supplies.

Without any substantial increase of the scope of the LBNF project!.

Conclusion

A very productive afternoon..

This will not be a quick and easy measurement.

Phasing, and multiple iterations will be required. Thus, looking for long term staging. And we will need help!

Interesting HEP experimental work is ahead of us !.

Your contribution will be essential,
Please, let us know if you want to participate!.